Data Assimilation Using Distributed Hydrologic Models for High-Resolution Analysis of Streamflow and Soil Moisture

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Soil moisture is a critical hydrologic state variable that exerts large control over water and energy balance in land-atmosphere systems over a wide range of space-time scales. As such, it is essential for any models in which soil moisture dynamics play a key role to be initialized and diagnosed with as accurate as possible soil moisture information. Soil moisture, however, is only very sparsely measured in-situ and usually not reported in real time. For these reasons, in operational hydrologic forecasting, soil moisture is almost always estimated indirectly from water balance calculations of hydrologic models based on precipitation, potential evaporation (PE) and streamflow, often with the aid of human forecasters to keep the model-simulated streamflow in line with the observed.

While streamflow is not a direct measure of soil moisture, it does represent space-time-integrated response of the basin to soil moisture, and is measured at many locations and reported in real time. As such, albeit indirect, streamflow observations are arguably the most widely available source of information for estimating soil moisture. In this work, we assess the potential of assimilating streamflow, in-situ soil moisture, precipitation, and PE data into distributed hydrologic models for high-resolution analysis of streamflow and soil moisture. The assimilation technique used is 4DVAR (Seo et al. 2003). The hydrologic models used are the heat transfer version of the Sacramento soil moisture accounting model (SAC-HT) and the kinematic-wave hillslope and channel routing models of the NWS Hydrologic Laboratory's Research Distributed Hydrologic Model (HL-RDHM) (Koren et al. 2004). The models operate on an approximately 4x4 km^2 grid and are forced by hourly precipitation and PE.

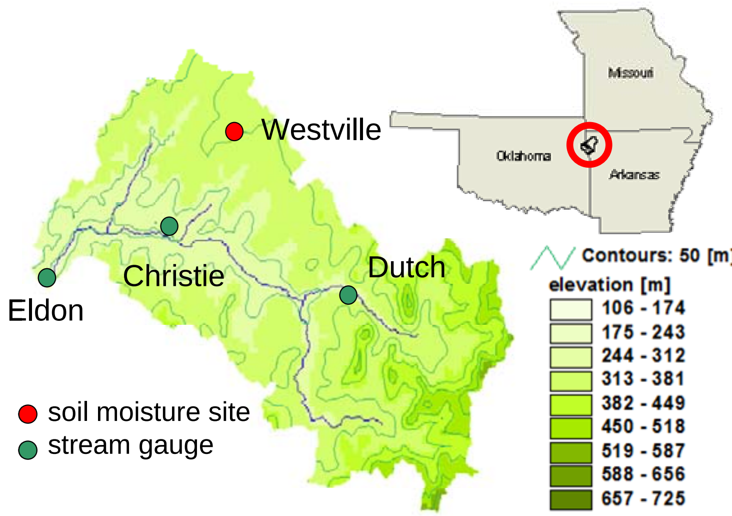

Figure 1 Study basin - Eldon of the area about 795 km^2.

Two synthetic and a real-world experiments were carried out in an ensemble framework to assess sensitivity of the potential of the data assimilation (DA) for analysis of streamflow and soil moisture to uncertainties in the model initial conditions and in the observations. The study basin is Eldon (ELDO2) in northeast Oklahoma (Figure 1). It is 795km^2 in size and has three USGS stream gauges (one at the outlet and two at interior points, Christie and Dutch) and one Oklahoma Mesonet soil moisture site at Westville. The precipitation data used are the operationally produced Stage III products at ABRFC. For PE, monthly climatology is used.

Results from the synthetic experiments show that assimilating streamflow, in-situ soil moisture, precipitation and PE data has large potential for high-resolution analysis of streamflow and soil moisture. However, its potency is sensitive to the uncertainty in the initial soil moisture conditions, the quality of observations and the goodness of the models (and their parameters). It is seen that, if the initial conditions are

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highly uncertain, soil moisture observations have larger positive impact than streamflow observations, but that, if the initial conditions are less uncertain, accurate streamflow observations have larger positive impact than soil moisture observations (Figure 2). Assimilating precipitation, in addition to streamflow and soil moisture observations, improves water balance calculations. If precipitation uncertainty is not properly accounted for, streamflow balance may be improved, but at the expense of deteriorated soil moisture balance. If precipitation has large uncertainty, assimilating soil moisture observations has large positive impact on analysis of soil moisture and streamflow; the more uncertain the initial conditions, the larger the impact. Results from the real-world experiment show that assimilating streamflow observations at both the outlet and interior locations generally improves streamflow prediction at those locations. Assimilating soil moisture observations have large positive impact on model soil moisture states when the model initial conditions are highly uncertain.

One of the next steps is to bring satellite-derived soil moisture information into the above analysis. To that end, NCEP/EMC and OHD are collaborating on assimilating satellite-derived soil moisture data into gridded SAC-HT using the Land Information System (LIS, Kumar et al. 2006) and assimilating the resulting model initial conditions into the above DA process for high-resolution analysis of streamflow and soil moisture that utilize all available data sources for soil moisture.

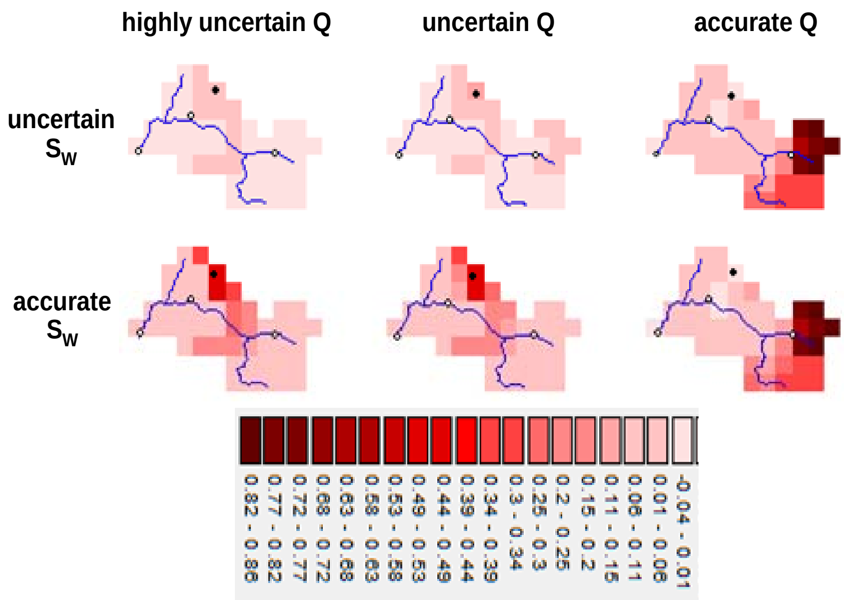

Figure 2 Skill scores for soil moisture analysis at 25cm depth with data assimilation (synthetic experiments) at three levels of uncertainty for streamflow at Eldon, Christie, and Dutch (Q) (from left to right: highly uncertain, uncertain and accurate) and two levels of uncertainty for soil moisture at Westville (Sw) (from top to bottom: uncertain and accurate), given the same uncertainty for initial condition.

Acknowledgments. We would like to thank the Oklahoma Climatological Survey for allowing the use of the Oklahoma Mesonet soil moisture data.

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